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Fuel taxes, driving, and CO₂ emissions: Quasi-experimental evidence



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Abstract

This paper studies the effects of a significant fuel tax increase on driving and therefore CO₂ emissions. Fuel taxes are a major policy tool to reduce road transport emissions. Despite the prevalence of fuel taxes, credible causal evidence of the effect of fuel taxes on driving and emissions is limited, and the reasons why existing estimates vary remain unexplored. Our research directly addresses these gaps in the literature by exploiting exogenous variation provided by Finland's 2012 energy tax reform. The reform increased the tax on diesel by almost 12 euro cents per litre, while the tax on gasoline was increased by less than 3 euro cents per litre. The reform allows us to utilize a quasi-experimental setting and compare the vehicle kilometers traveled by diesel- and gasoline-powered cars to identify the impacts of fuel taxes. We employ a large representative data set of about 0.7 million cars, which contains car odometer readings from mandatory car inspections starting from 2008. Our estimates indicate a clear reduction in vehicle kilometers traveled by diesel cars due to reform-induced increases in diesel prices. In our heterogeneity analysis we observe that a large part of the response originates from car owners that reside in urban rather than rural environments.

Keywords: Fuel taxes; Fuel consumption; Fuel tax elasticity; Mileage; CO₂ Emissions; Road transport emissions

JEL Codes: J31, J38, D22

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1 Introduction

As countries are seeking effective ways to combat climate change and de-carbonise, transportation emissions play a crucial role. For instance, EU legislation mandates that EU member states reduce greenhouse gas emissions from the sectors not regulated by the EU emissions trading scheme by 39% by 2030. Emissions from road transport form a major part of these emissions in many member states. On the other hand, in the US, fuel tax rates have been at significantly lower levels.

In theory, fuel taxes are an effective way to incentivize less driving and the deployment of more fuel-efficient cars. In practice, different countries rely on different levels of fuel taxation in their policy toolkit. But research-based evidence to advice which policy stance is more effective in reducing emissions is scarce, because causal evidence on the effects of fuel taxation is limited. Recently, for example Gillingham and Munk-Nielsen (2019), Goetzke and Vance (2021), Langer, Maheshri and Winston (2017) and Tilov and Weber (2023) have analyzed the impact of fuel prices on vehicle kilometers traveled and gasoline consumption utilizing naturally varying fuel prices combined with instrumental variable strategies, but not exogenous variation in prices originating from fuel tax reforms. Causal evidence on the extent to which fuel taxes reduce driving or CO₂ emissions from transportation remains limited. Moreover, given the unpopularity of fuel taxes among voters and the possibly regressive nature of the tax, more information is needed on the possible heterogeneous impacts of fuel taxes across the urban versus rural axis and the income distribution.

Our paper addresses these gaps in the literature and provides credibly causal evidence on the effect of fuel taxes. We exploit quasi-experimental variation originating from Finland’s 2012 tax reform, which increased the tax on diesel by almost 12 euro cents per litre and the gasoline tax by less than 3 euro cents. This set up allows us to credibly compare log of the vehicle kilometers traveled of cars that operate with diesel to cars that operate with gasoline, as the fuels are not interchangeable. In Finland, as well as in many other EU countries, diesel vehicles are common as passenger vehicles as well, not just as heavy transport vehicles. We have access to detailed individual-level data containing the

kilometers travelled of each car, based on mandatory car inspections, with over 4 million observations. Our results show parallel pre-trends and a sizeable decline in the kilometers travelled by diesel cars as a response to reform-induced hike in diesel price, characterized by a price elasticity estimate of around -0.8. Thus, higher diesel prices reduced CO₂ emissions from diesel cars through lower VKT.

In more detail we utilize the same 2012 diesel tax reform in Finland that was studied by Harju et al. (2022), who focused on the pass-through of the tax to consumer prices on average and along the income distribution and the rural-urban spectrum. This previous research shows that diesel and gasoline prices can be meaningfully compared as they develop in parallel prior to the reform, and that the diesel tax was only slightly less than fully passed through to diesel prices. Thus, the reform produced a clear gap between diesel and gasoline prices relative to before the reform prices. The tax reform allows for quasi-experimental analysis because diesel and gasoline are sold in the same gas stations likely having the same pricing behavior, but the tax reform created exogenous variation between the prices of the two fuels. In addition, a gasoline car cannot operate on diesel or vice versa. Moreover, most car makers produce both gasoline and diesel cars, even of the same model. In the Finnish car fleet, there are large numbers of both diesel and gasoline powered cars that have otherwise similar characteristics. Thus, the two types of cars and their owners are similar and form a credible set up with treatment (diesel cars) and a matching control group (gasoline cars). The comparison allows us to control for common factors that contemporaneously affect all cars in the Finnish car fleet, such as changes in global oil prices or changes in the macroeconomic conditions in Finland.

For the analysis, we construct a data set of about 700 000 cars observed on average about 6 times for the years between 2008 and 2017. The data set contains vehicle identification numbers and car odometer readings from car inspections, as well as a rich set of car characteristics, such as engine power (diesel or gasoline) and size, CO₂ intensity, make, model, and age of the car. The odometer readings allow us to form annual vehicle kilometers traveled by each car, a key outcome variable in the study. The readings are recorded in car inspections by an inspection company and are not self-reported mea-

tures. Thus, they provide very accurate observations of odometer readings. As we also observe vehicle identification numbers, we can track how the odometer readings of each car develop over time. The resulting data allows us to provide a good measure of the mileage development in the Finnish car fleet. We also link these data to individual-level data of car owners and match that with full population data on employment histories, income, place of residence and demographic characteristics to study the heterogeneity in responses to the 2012 reform.

We form our analysis sample in the following way. We first note that diesel and gasoline cars have different distributions in vehicle kilometers traveled (VKT). Moreover, the distributions have very long right tails. For these reasons, we trim the top 1% of observations from the VKT distributions by motive power, and analyze the average responses in logs. An additional data restriction is that prior to 2013 we only have a (large) sample of cars, after that the full population of cars. To make the pre-and post 2013 population of cars comparable, we constrain the analysis data to cars that have a VKT measure before and after the 2012 reform.

We then examine the impact of the 2012 reform on VKT of diesel cars relative to those of gasoline cars. In the analysis sample the log VKT develop relatively well in parallel prior to the reform and the log VKT of the gasoline cars develop smoothly over the 2012 reform. Instead, there is a sizeable decline in the log VKT of the diesel cars after the reform of about 5%. Because the event-study shows that the deviation around the general trend occurs only at the time of the reform, we interpret it as a causal effect of the 2012 reform increasing diesel prices relative to gasoline prices. In order to quantify the response, we provide a back-of-the-envelope price elasticity calculation, which produce price elasticity estimate of -0.8 for VKT. The elasticity is sizeable, towards the higher end estimated in the reduced form literature, although the earlier literature has not been able to utilize exogenous variation in taxes the way the current study does. Part of the explanation for the higher elasticity is that our analysis excludes the newest cars from the sample, as they are exempt from vehicle inspections and odometer data are thus not available. The response to fuel taxes could be higher among slightly older cars than

among newer cars. In any case, taking this estimate at face value suggests that fuel tax is an effective way to reduce driving and thus emissions.

We also study the heterogeneity of responses across the income distribution and between rural and urban locations: the estimated elasticity in rural locations is -0.7 and it is -1 in urban locations suggesting significantly more elastic price elasticity in urban locations. These results reveal that a large part of our average effect originates from those car owners residing in urban rather than rural areas. The heterogeneity along the income gradient does not reveal any differences in the VKT response.

We contribute to an increasingly active literature studying the impacts of fuel prices on either driving or fuel consumption (Gillingham and Munk-Nielsen (2019), Klier and Linn (2015), Goetzke and Vance (2021) Langer, Maheshri and Winston (2017) and Tilov and Weber (2023). See also a literature survey by Seppänen et al. (2022)). The previous literature that is able to rely on variation in fuel prices or instrumental variables has produced a relatively large range of price elasticities. Our elasticity estimates are towards the higher end of the elasticities in the previous literature. One reason for the difference could be that when there is no clear and exogenous source of variation in prices, the estimates could be downward biased. Nevertheless, our contribution to this literature is to highlight that fuel taxes can be an even more effective tool to reduce CO₂ emissions from transportation than one might have concluded based on previous literature. We also contribute by studying the effect of fuel taxes in Europe, where the fuel tax levels are much higher than for example in the US where most of the previous literature originates from.

Our study also relates to studies estimating how fuel price variation or different policies affect road transport emissions. For example, Klier and Linn (2015) study how vehicle taxes affect the CO₂ emissions of new cars purchased.

The paper proceeds by discussing the relevant institutions, data and identification strategy accompanied with our main results.

2 Institutional background

2.1 Passenger vehicle fuels and fuel market in Finland

The most common passenger vehicle fuel in Finland is gasoline, as in other European countries. Diesel is also widely used both in Finland and in Europe overall: approximately 22% of passenger vehicles in Finland and 35% of passenger vehicles in the European Union ran on diesel in the tax reform year 2012.

Gasoline cannot be used in a diesel engine, and vice versa. Thus, it is not possible to substitute one fuel for the other in a given vehicle. Retail gas stations typically dispense diesel and gasoline from the same fuel pumps, but from separate nozzles that are clearly labeled. As for the fuel market, Finland has no oil production of its own and only has two refineries. There are six main station chains, all of which serve the entire country. Most gas stations belong to one of the six station chains. Each station chain sells the same diesel and gasoline blends throughout its network in Finland.

2.2 Fuel taxes and the 2012 reform

Finland collects both excise taxes and value added taxes on transport fuels. While the excise taxes have long been largely fiscal in nature, they have also included a carbon tax since the 1990s. In 2011, the carbon tax component was made explicit, and the excise tax has since then included a fiscal component based on the energy content of the fuel and a small security of supply fee, and a carbon tax component based on the emissions from fuel combustion. Prior to 2011, the excise tax included a basic tax, a security of supply fee, and a surplus tax based on the carbon content of the fuel. Gasoline and diesel sold in the retail market blend pure gasoline and diesel with biofuels and additives, which are taxed at lower rates. The excise taxes on retail blends thus differ slightly from those on pure diesel and gasoline. Transport fuels are also subject to value added taxes, payable on the excise tax inclusive price.

The 2011 change in tax structure was followed by a notable increase in the tax on diesel in January 2012, when the climate ambition of the tax was augmented substantially: the

carbon tax on diesel was increased from 20 euros/tCO₂ to 60 euros/tCO₂. This amounted to a 10.55 euro cents per liter increase in the excise tax on diesel. The carbon tax on gasoline was already 50 euros/tCO₂, and was now also increased to 60 euros/tCO₂, which amounted to a 2.34 euro cents per litre increase in the excise tax on gasoline. Accounting for the value added tax, which was 23 % in both 2011 and 2012, the carbon tax increase amounted to overall tax increases of 11.80 cents per liter for diesel and 2.66 cents per liter for gasoline.

Figure 3 shows the development of consumer prices of diesel and gasoline for a few years over the 2012 reform, as well as, how the excise taxes on gasoline and diesel develop over the same time period. The figure clearly shows the jump in the excise tax for diesel as an upward jump, while there is only a modest and smooth increase in the trend for the excise tax on gasoline. The price series shows these changes clearly, and that there is another decline between the price gap for gasoline and diesel already in 2011. This was caused by the change in tax structure in 2011 as described above. When later estimating the price elasticity of demand we use only the excise tax induced change in price variation.

2.3 Other contemporary policy changes

Other policy changes were implemented in the 2009-2015 study period that could also affect fuel prices. The excise taxes on gasoline and diesel changed again in January 2014: the tax on gasoline was increased by 2.25 euro cents per liter and that on diesel by 2.71 euro cents per liter. Both increases were in the carbon tax component of the excise tax. These changes were small relative to the 2012 reform and almost equal for gasoline and diesel and hence are unlikely to confound our identification design. Other changes in the tax law in the study period involved dividing biofuels into different subcategories and specifying excise tax levels for the new subcategories (Finlex 1399/2010, Finlex 1131/2013).¹

Biofuel policies can also affect gasoline and diesel prices. Finland has had a biofuel mandate in place since January 2008. The biofuel mandate stipulates a minimum share

¹When in 2009 there were only 10 biofuel subcategories, in 2011 there were 24 and in 2014 already 27 subcategories (Finlex 1399/2010, Finlex 1131/2013).

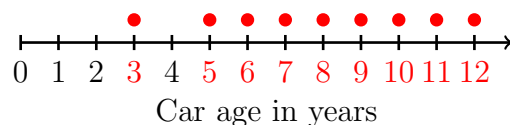
of biofuel components that the total amount of diesel and gasoline blends supplied to the retail market by a fuel distributor has to contain over the course of a year. The initial biofuel mandate in 2008 was 2% (Finlex 446/2007). Over our study period, the mandate increased to 4% in 2009, 6% in 2011, 8% in 2015, and 10% in 2016 (Finlex 1056/2009, Finlex 1420/2010). These changes were also small.

3 Data

3.1 Data on vehicle kilometers traveled

To estimate the effects of the diesel tax increase on driving, we construct a dataset containing estimates of annual vehicle kilometers traveled (VKT) for Finnish passenger cars² during the years 2009–2015. The annual VKT estimates are based on car-level observations of odometer readings starting from the year 2008. The odometer reading data come from mandatory vehicle inspections. In Finland, all cars are required to be inspected at regular intervals throughout their lifespan. In addition to evaluating the condition of the car, an inspection always involves checking and recording the car’s odometer reading. The lengths of the inspection intervals depended on the age of the car and ranged from one to three years during our sample period 2009–2015, as seen in Figure 1. All cars had to be inspected for the first time three years after initial registration. The second inspection was required two years later, and after that an inspection was required every year.

Figure 1: Mandatory inspection intervals by car age



Our vehicle inspection data come from two sources: 1) For the period 2008–2012,

²According to Finnish law, passenger cars are motor vehicles that are primarily used for transporting people and have at least four tires, a maximum speed exceeding 25 kilometers per hour and no more than eight seats in addition to the driver’s seat. Many recreational vehicles fall into this category but we do not include them in our sample of passenger cars.

from the largest vehicle inspection provider in Finland, and 2) from 2013 onward, from the vehicle register maintained by the Finnish Transport and Communications Agency Traficom. The Traficom data include all cars that were inspected at any point since 2013. The first data source, on the other hand, have at least one odometer reading for about 58 percent of all passenger cars in Finland during 2008–2012. Both data sources include either a license plate number or a vehicle identification number (VIN) for each vehicle, which allows us to identify vehicles and follow them in both data sources and over time.

We construct our estimates of vehicle-level annual VKT by allocating the VKT between consecutive inspections to the calendar years between the inspections. Specifically, for every inspection interval and car, we first calculate the daily average VKT by dividing the change in the odometer reading with the number of days between the inspections. We then identify the calendar years that the inspection interval overlaps and assign a VKT to each calendar year by multiplying the daily average VKT by the number of days for which the inspection interval and calendar year overlap.

This procedure produces a total of nearly 12 million annual VKT estimates for about 630,000 diesel cars and 2,070,000 gasoline cars for the years 2009–2015. However, around 2.3 million of these annual VKT estimates are incomplete in that they do not include all the kilometers driven during the year. This is because the first and last odometer reading observation in our data do not usually land on the first or last day of the year. As a result, we have annual VKT estimates for full calendar years for about 540,000 diesel cars and 1,840,000 gasoline cars. We describe below further restrictions we made to create the analysis data.

3.2 Car owner data

Finally, we also use individual-level population data provided by Statistics Finland to obtain information on the owner of each car right before the reform on December 31, 2011. This allows us to determine whether each car was owned by a private individual or a firm and whether the car was in private or commercial use. In addition, we use individual-level information on each pre-reform car owner to analyze potential heterogeneity in driving

responses to the diesel tax cut with respect to the degree of urbanization and income.

The degree of urbanization is measured using a seven-class urban-rural classification provided by the Finnish Environment Institute. The entire country of Finland can be divided into 250 meters by 250 meters statistical grid cells, each of which then falls into one of the following categories: inner urban area, outer urban area, peri-urban area, local centers in rural areas, rural areas close to urban areas, rural heartland areas, and sparsely populated rural areas. Only the first two of these are unambiguously urban, and thus we categorize each car with an owner in one of these locations as urban and all the other as rural. We also determine the income quintile of each pre-reform car owner using information on disposable household income.

3.3 Sample restrictions

Our main approach to studying the effects of the diesel tax increase involves a comparison of changes in VKT between diesel and gasoline-powered cars. To ensure that these two types of cars in our data are comparable, we make four restrictions to the sample we include in our analysis. First, we keep for each car only the years for which we have VKT coverage for the entire calendar year. This essentially means that we ignore annual VKT estimates created for the first and last year each car appears in the inspection data. We do this so that we do not have to predict the VKT for the remainder of the year. In our data we observe a clear seasonal pattern in VKT such that cars are usually driven more during the summer. Thus, simply extrapolating VKT from a specific time during the year to the full calendar year would induce bias to the estimates.

Second, in our analysis we want to focus on regular passenger cars owned by individuals. To achieve this, we exclude cars that were owned by firms or were in commercial use before the reform on the last day of 2011. Individuals and firms might differ from each other vastly in how they respond to fuel tax increases. Furthermore, cars in commercial use are often diesel-powered because Finnish taxes on diesel are considerably lower than those on gasoline, making diesel a cheaper alternative for those who drive long distances. Only keeping privately-owned passenger cars in 2011 leaves us with close to 430,000 diesel

cars and 1,700,000 gasoline cars.

Third, we only keep cars for which we can estimate annual VKT for at least one calendar year both before the reform in 2009–2011 and after the reform in 2012–2015. By doing this, we can estimate how VKT changed for cars that were in the vehicle fleet before the reform, and the analysis is not complicated by the influx of new cars after the reform. Forcing cars to appear in the data both before and after the reform also mitigates any potential selection bias arising from the fact that our pre and post-reform data come from different sources.

Obtaining annual VKT estimates on both sides of the reform requires having odometer reading observations for at least two calendar years during both pre and post reform years. This restriction, while mandatory, unfortunately reduces our sample size the most, leaving us with about 90,000 diesel cars and 610,000 gasoline cars. The sharp drop in the number of cars is explained by two factors. On the one hand, cars in Finland are not inspected every year, as demonstrated in Figure 1. On the other hand, the odometer readings data for the first half of our sample period was sourced from a single inspection provider and covers only about half of all Finnish cars.

Finally, to reduce bias arising from erroneous odometer readings, we drop the top percentile of our VKT estimates separately for diesel and gasoline-powered cars. The odometer readings recorded during vehicle inspections include some mistakes that appear to be a result of human error. Readings often have extra zeros or other clear errors due to them being manually recorded. As a consequence, some annual VKT estimates are in the millions of kilometers per year. For reference, a typical car engine usually has a lifespan of a few hundred thousand kilometers. In our data, the 99th percentile of annual VKT is about 54,000 kilometers for diesel cars and 33,000 for gasoline cars.

Our final sample includes 92,164 diesel cars, 606,190 gasoline cars and a total of 4,325,169 annual VKT observations. The number of observations and other descriptive statistics are presented in Table 1. One can see from the table that while diesel cars are clearly fewer in number in the data, they have on average equally as many annual VKT observations as gasoline cars do. Diesel and gasoline cars are also very similar in age,

Table 1: Descriptive statistics

	Diesel	Gasoline	Total
N observations	567,280	3,757,889	4,325,169
N cars	92,164	606,190	698,354
N observations per car	6.2	6.2	6.2
Mean annual VKT	20,826	11,408	12,643
Mean registration year	2000.7	1999.1	1999.3

Notes: Number of observations refers to car-year VKT observations. Mean annual VKT and registration year are averages over the whole observation period 2009–2015.

with diesel cars only about 1.5 years younger. The average car in our sample was around 10 years old at the start of our sample period in 2009. Although a fairly high car age, it matches the average age of all cars in Finland very closely. One aspect in which diesel and gasoline are clearly different is how much they are driven. Annual VKT for diesel cars is on average more than 80 percent higher than annual VKT for gasoline cars. This likely reflects the fact that, during our analysis period, diesel cars were cheaper to drive because of lower taxes and better fuel economy.

4 Methods

4.1 Difference-in-differences

The main aim of this paper is to estimate the effects of the 2012 diesel tax reform on vehicle kilometers traveled (VKT). We apply a difference-in-differences (DiD) approach by comparing changes in the log of VKT between diesel and gasoline cars before and after the 2012 reform. Specifically, we estimate the following regression model:

$$\log(VKT_{it}) = \sum_{\tau=2009, \tau \neq 2011}^{2015} \beta_{\tau} \mathbb{1}[t = \tau] D_i + \varphi D_i + \lambda_t + \epsilon_{it} \quad (1)$$

The main outcome variable is the log of annual VKT by car i in calendar year t . D_i is 1 for diesel cars and 0 for gasoline cars, λ_t represent calendar year fixed effects and ϵ_{it} is the error term. The coefficients of interests are β_{τ} , which can be interpreted as the causal effect of the diesel tax increase on log VKT, assuming parallel trends in the log of

diesel and gasoline VKT. We also estimate a simple pre vs post version of the DiD model to estimate the average treatment effect over the whole post-reform period.

We also analyze heterogeneity in the elasticity of driving with respect to fuel prices in two dimensions, the degree of urbanization and income. To achieve this, we use information on the residential location and income of the 2011 owner of each car in our sample. We estimate a simple pre vs post DiD model which we modify slightly by adding an interaction term with our measures of the degree of urbanization and income:

$$\begin{aligned} \log(VKT_{it}) = & \delta D_i * Post_t * H_i + \gamma_1 D_i * Post_t + \gamma_2 D_i * H_i + \gamma_3 Post_t * H_i \\ & + \gamma_4 D_i + \gamma_5 Post_t + \gamma_6 H_i + \gamma_7 + \eta_{it} \end{aligned} \quad (2)$$

Now, $Post_t$ equals 1 for years 2012–2015 and 0 for years 2009–2011, and H_i is one of our heterogeneity dimensions, either a dummy for urban areas or a five-category variable containing income quintiles. If the assumption of parallel trends holds in every category of each heterogeneity dimension, γ_1 gives the causal effect of the tax increase on log VKT in the baseline category and δ the difference in the effect in the other categories relative to the baseline.

4.2 Elasticities

Using the results from estimating the models in Equations 1 and 2 we provide estimates of the elasticity of VKT with respect to fuel prices. Specifically, we divide the VKT treatment effect estimates by diesel price treatment effect estimates from a similar model estimated on the log of diesel and gasoline prices. The validity of using this DiD approach to estimate the effect of the diesel tax increase on diesel prices is discussed extensively in Harju et al. (2022).

Following Harju et al. (2022), we estimate the DiD model for fuel prices only using price data from 2011 and 2012 to obtain the most reliable estimate of the effect of the tax increase on prices. There are two main reasons why we do not use data before 2011 or after 2012. First, the whole fuel tax system was overhauled in 2011 when the CO₂ tax

and separate taxes for biofuels were introduced, as described in Section 2.2. Second, in 2011, the type of gasoline sold in Finland was changed from 95E5, containing a maximum of 5 percent of ethanol, to 95E10, with a maximum ethanol concentration of 10 percent. This change initially caused uncertainty about the compatibility among drivers, and thus might have had an effect on the price of gasoline at the turn of the year 2011. Both of these factors might explain why the price gap between gasoline and diesel shrunk already in 2011, before the 2012 tax reform, as seen in Figure 3b in the Appendix.

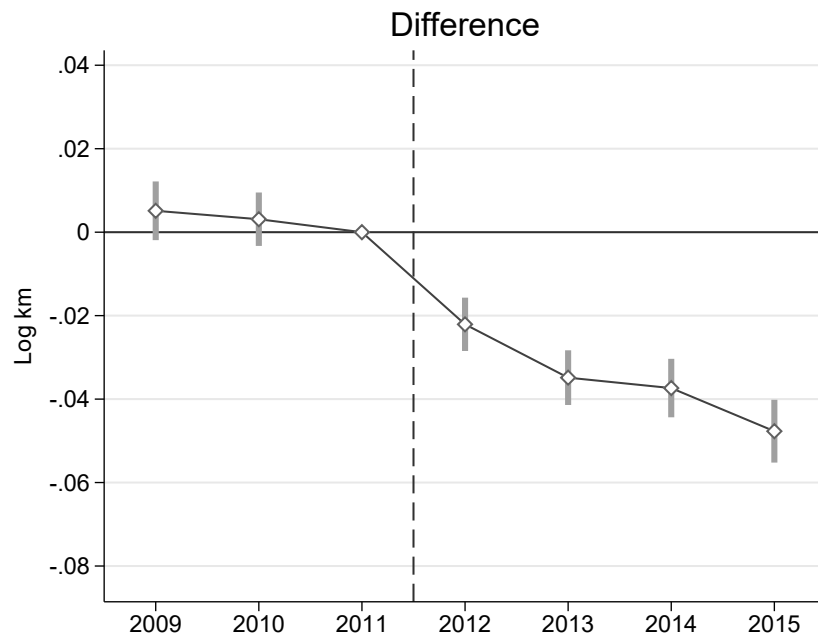
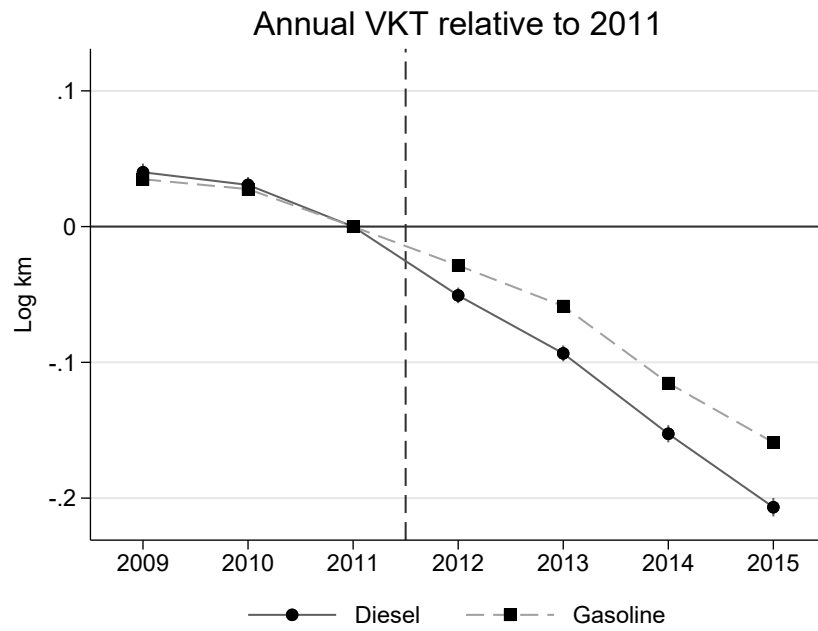
Estimating the DiD model on the log of fuel prices, we find that diesel prices increased by 0.057 log points more than gasoline prices. We use this as the denominator in our elasticity calculations. It should be noted, however, that interpreting the elasticity estimates is complicated by the concurrent gasoline tax increase in 2012. To get unbiased elasticity estimates, we have to assume that the elasticity of driving with respect to fuel prices is identical across both diesel and gasoline cars, as shown by Harju et al. (2022). The results, however, are not very sensitive to minor deviations from this assumption due to the gasoline tax increase being fairly small in magnitude relative to the diesel tax increase.

5 Main results

We start by visual inspection of the trends in the log of annual VKT between diesel and gasoline cars in the upper panel of Figure 2. Prior to the reform, the changes in log VKT for both fuel types follow an almost perfectly parallel trend, which provides evidence supporting the plausible validity of our empirical approach. After the reform, log VKT for diesel cars immediately falls below that for gasoline cars and remains at a lower level throughout our post-reform period. The downwards sloping curves in the upper panel of Figures 2 are largely explained by the fact that we are looking at a sample of cars that is fixed before the reform due to the restriction on the number of inspections. As cars get older, they are generally driven less.

The lower panel of Figure 2 shows the difference between these two lines as a result

Figure 2: Effects of the Reform on log VKT



Odometer readings for at least 2 years pre and post reform

of estimating the model in Equation 1. The results are also presented in more detail in Table 2. The figure reveals there is no statistically significant difference in the trends in the pre-reform period. Log VKT for diesel immediately starts falling faster than log VKT for gasoline and the gap between the the fuel types widens slightly over time, going from around -0.02 to almost -0.05. Results from the pre vs post DiD model are presented in Table 5 in the Appendix. The average treatment effect over the whole post-reform period is nearly -0.04.

However, the gradual increase in effect size might not be real but instead entirely mechanical and attributable to the fact that some cars have inspection intervals longer than one year. If cars have longer inspection intervals, we cannot detect changes in VKT at the annual level, and thus changes appear more gradually. This point is demonstrated by Figure 4 in the Appendix, which shows results from estimating model 1 on a sample of cars for which we observe four inspections before and after the reform, meaning every year during our sample period. In this figure, the effect of the reform is stable starting from the year 2013. In both figures diesel cars are driven by about 5% less than gasoline cars by year 2015.

Table 2 also presents estimates of the elasticity of VKT with respect to fuel prices separately for all post-reform years. Column (1) of Table 2 has results obtained from our main sample, in which cars have odometer readings for at least two years before and after the reform. In addition, column (2) includes results from the more restricted sample with four years of inspections on both sides of the reform. In column (1), our preferred estimates come from the later post-reform years because of the possibility that the effect size increases mechanically due to data limitations. The elasticity estimate of -0.833 in 2015, our preferred elasticity estimate, is very similar to the estimates for years 2013–2015 in column (2).

These elasticity estimates fall at the higher end of estimates reported in the literature (see e.g. Goetzke and Vance, 2021; Tilov and Weber, 2023; Khanna, Dubernet and Jochem, 2025). There are at least three potential reasons for this. First, our setting uses plausibly exogenous variation in prices caused by the tax increase. In contrast, many

Table 2: Difference-in-differences results

	(1) 2 readings pre and post	(2) 4 readings pre and post
Diesel*2009	0.005 (0.004)	0.001 (0.010)
Diesel*2010	0.003 (0.003)	0.008 (0.011)
Diesel*2012	-0.022*** (0.003)	-0.039*** (0.011)
Diesel*2013	-0.035*** (0.003)	-0.054*** (0.011)
Diesel*2014	-0.037*** (0.003)	-0.048*** (0.012)
Diesel*2015	-0.048*** (0.004)	-0.055*** (0.013)
Elasticity in 2012	-0.386	-0.676
Elasticity in 2013	-0.609	-0.938
Elasticity in 2014	-0.652	-0.840
Elasticity in 2015	-0.833	-0.967
Observations	4,315,467	617,166

Notes: This table includes results from estimating the model in Equation 1. The dependent variable is the log of annual VKT. The elasticity estimates are the result of dividing the Diesel*Year coefficient estimates by 0.057, the DiD estimate of the change in the log of diesel price relative to the log of gasoline price between 2011 and 2012. Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

papers rely on other types of price variation that might be less exogenous, leading to biased estimates. Second, we analyze the effects of a very large tax increase that was both very salient and also permanent. Third, our analysis data excludes the newest cars, and the elasticity might be higher in our analysis data than in data that includes also the newest cars. Both of these factors might lead to a higher price sensitivity.

6 Heterogeneity

Results on treatment effect heterogeneity with respect to the degree of urbanization and income from estimating the model in Equation 2 are presented in Tables 3 and 4.

Table 3: Difference-in-differences results: urban vs rural

	(1) 2 readings pre and post	(2) 4 readings pre and post
Diesel*Post	-0.026*** (0.002)	-0.042*** (0.007)
Diesel*Post*Urban	-0.013** (0.004)	-0.015 (0.014)
Observations	4243825	604889
Elasticity rural	-0.462	-0.727
Elasticity urban	-0.691	-0.990

Notes: This table includes results from estimating the model in Equation 2. The dependent variable is the log of annual VKT. The elasticity estimates are the result of dividing the Diesel*Post coefficient estimates by 0.057, the DiD estimate of the change in the log of diesel price relative to the log of gasoline price between 2011 and 2012. Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The results indicate that the effect is heterogeneous along the urban-rural axis such that a large part of the main effect is coming from cities rather than from rural areas. The main effect in column (1) indicates a 2.6% reduction in diesel VKT while in urban areas the effect is 1.3% larger. The point estimate for urban areas is of similar size than in column (1), but it is not statistically significant likely due to the significantly smaller sample size in column (2). Also the elasticity estimates are clearly different in urban and rural areas. In column (2) the elasticity estimate for rural areas is -0.7 while it is -1 for

Table 4: Difference-in-differences results: car owner income quintile

	(1) 2 readings pre and post	(2) 4 readings pre and post
Diesel*Post	-0.046*** (0.007)	-0.059** (0.021)
Diesel*Post*2nd quintile	0.016 (0.009)	0.012 (0.026)
Diesel*Post*3rd quintile	0.010 (0.008)	0.009 (0.025)
Diesel*Post*4th quintile	0.013 (0.008)	0.017 (0.024)
Diesel*Post*5th quintile	0.011 (0.008)	0.008 (0.024)
Observations	4240434	604292
Elasticity 1st quintile	-0.801	-1.037
Elasticity 2nd quintile	-0.518	-0.828
Elasticity 3rd quintile	-0.624	-0.884
Elasticity 4th quintile	-0.582	-0.743
Elasticity 5th quintile	-0.604	-0.897

Notes: This table includes results from estimating the model in Equation 2. The dependent variable is the log of annual VKT. The elasticity estimates are the result of dividing the Diesel*Post coefficient estimates by 0.057, the DiD estimate of the change in the log of diesel price relative to the log of gasoline price between 2011 and 2012. Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

urban areas. In column (1) the difference in the elasticity estimates is similar, although both estimates are lower, likely due to including years 2012 through 2014 in the estimate, where the effect is smaller due to the mechanical effect discussed in Section 5.

The higher price sensitivity of mileage in urban areas could be driven by better possibilities to substitute driving one's own car with other means of transportation. It would be natural for consumers to be more responsive to price variation if other forms of transportation are more readily available, such as public transportation.

Instead, as reported in Table 4, we do not find a significant difference in the effect across different income quintiles.

7 Conclusions

In this paper we analyze to what extent higher fuel prices reduce vehicle kilometers traveled. We leverage the 2012 reform in Finland that increased the fuel tax for diesel relative to that of gasoline, providing a quasi-experimental setting for our analysis. The results indicate a significant decline in log VKT for diesel cars relative to gasoline cars due to the reform. Our preferred price elasticity estimation suggests that the price elasticity of driving could be as high as -0.8.

Lower VKT is mechanically connected to lower CO₂ emissions. Thus, fuel taxes do seem to be effective means of reducing CO₂ emissions from transportation, as theory suggests.

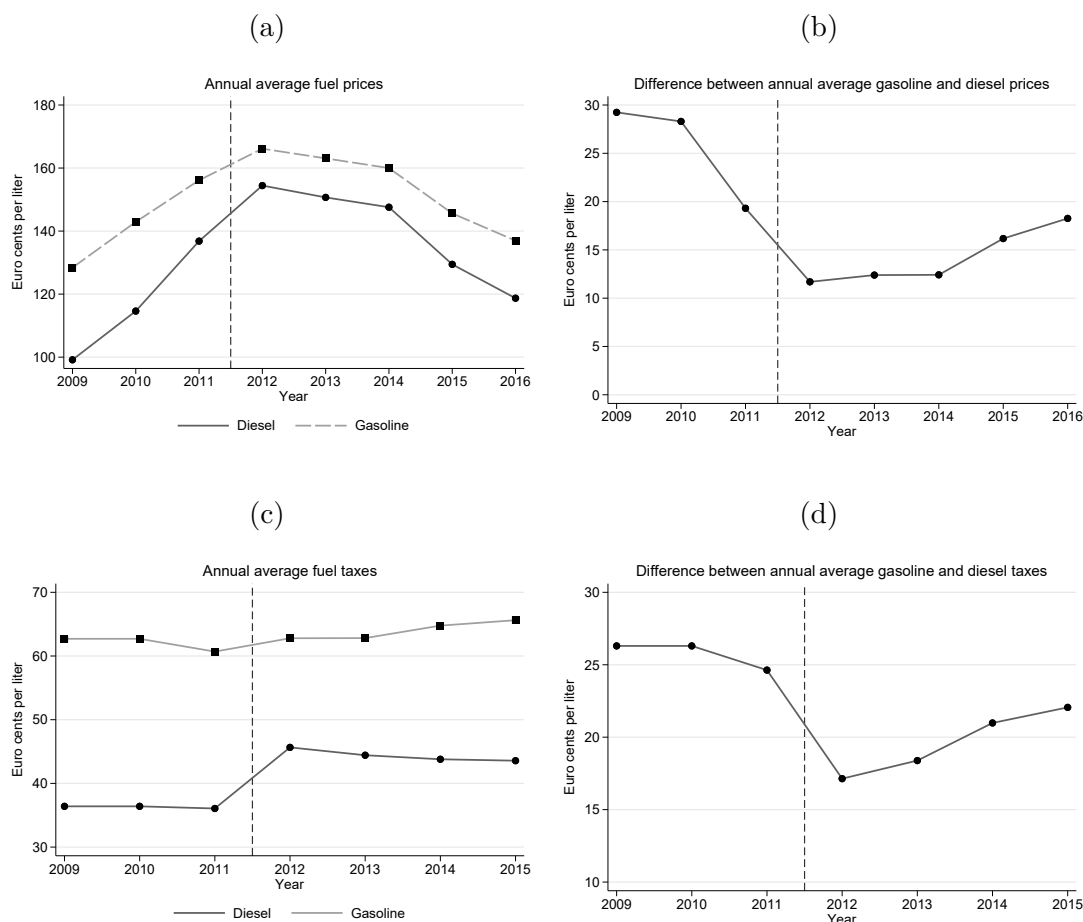
In terms of mechanisms behind the main result, we find that car owners residing in urban areas are more responsive than those residing in rural areas. This suggests that more readily available public transportation and other means of transportation than using one's own car could make driving more sensitive to prices and thus more responsive to fuel taxes.

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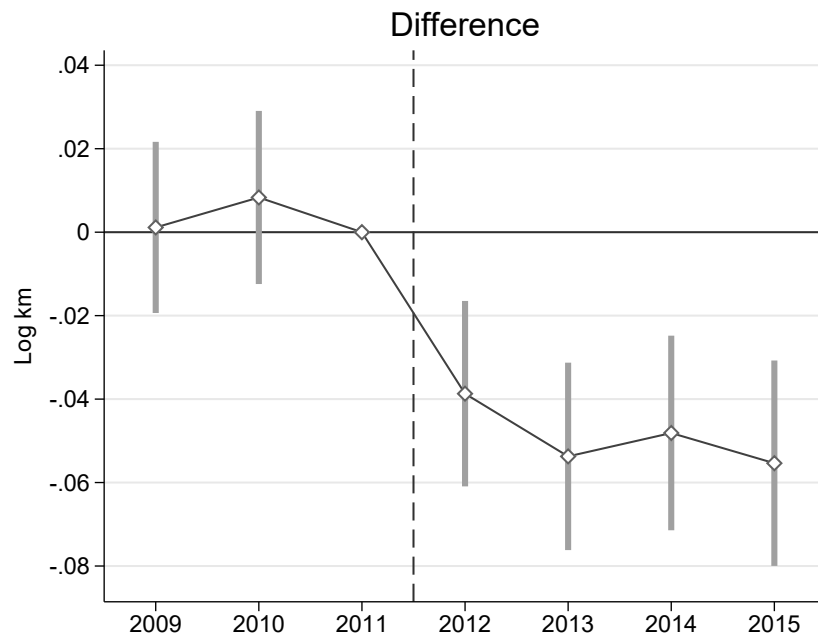
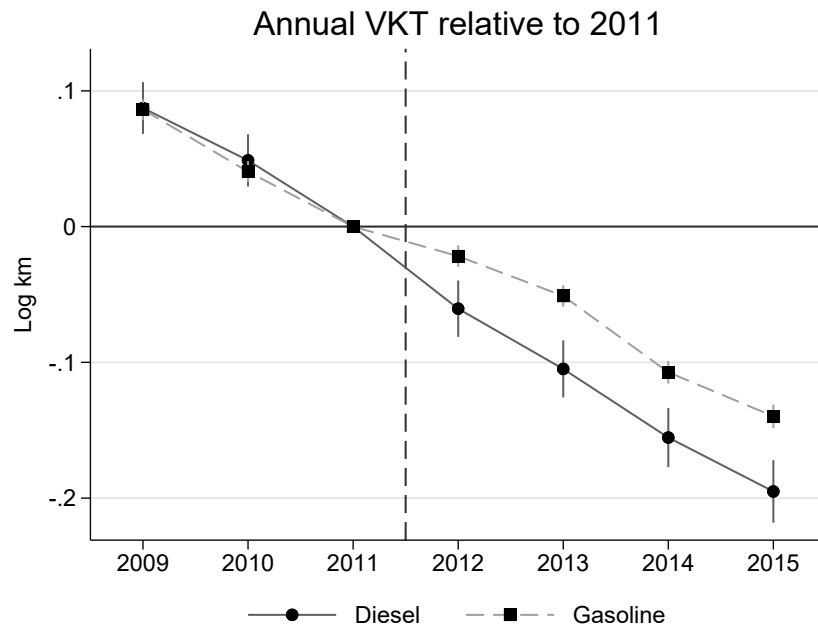
Appendix

Figure 3: Development of gasoline and diesel fuel prices and excise taxes, 2009-2015



Notes: Panel (a) depicts the evolution of annual average gasoline and diesel prices from 2009 to 2015 and panel (b) shows their difference. Panel (c) displays diesel and gasoline excise taxes and panel (d) depicts their difference by year from 2009 to 2015. The 2012 energy tax reform is visible as a jump in the diesel tax line in panel (c) and as a decrease in the difference in panel (d).

Figure 4: Effects of the Reform on log VKT



Odometer readings for at least 4 years pre and post reform

Table 5: Difference-in-differences results: pre vs post

	(1) 2 readings pre and post	(2) 4 readings pre and post
Diesel*Post	-0.037*** (0.002)	-0.052*** (0.006)
Observations	4315467	617166
Elasticity	-0.646	-0.903

Notes: This table includes results from estimating a simplified pre vs post version of the model in Equation 1. The dependent variable is the log of annual VKT. The elasticity estimates are the result of dividing the Diesel*Post coefficient estimates by 0.057, the DiD estimate of the change in the log of diesel price relative to the log of gasoline price between 2011 and 2012. Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.